An Energy Efficiency Workshop & Exposition

Palm Springs, California

Wind Energy for Federal Agencies

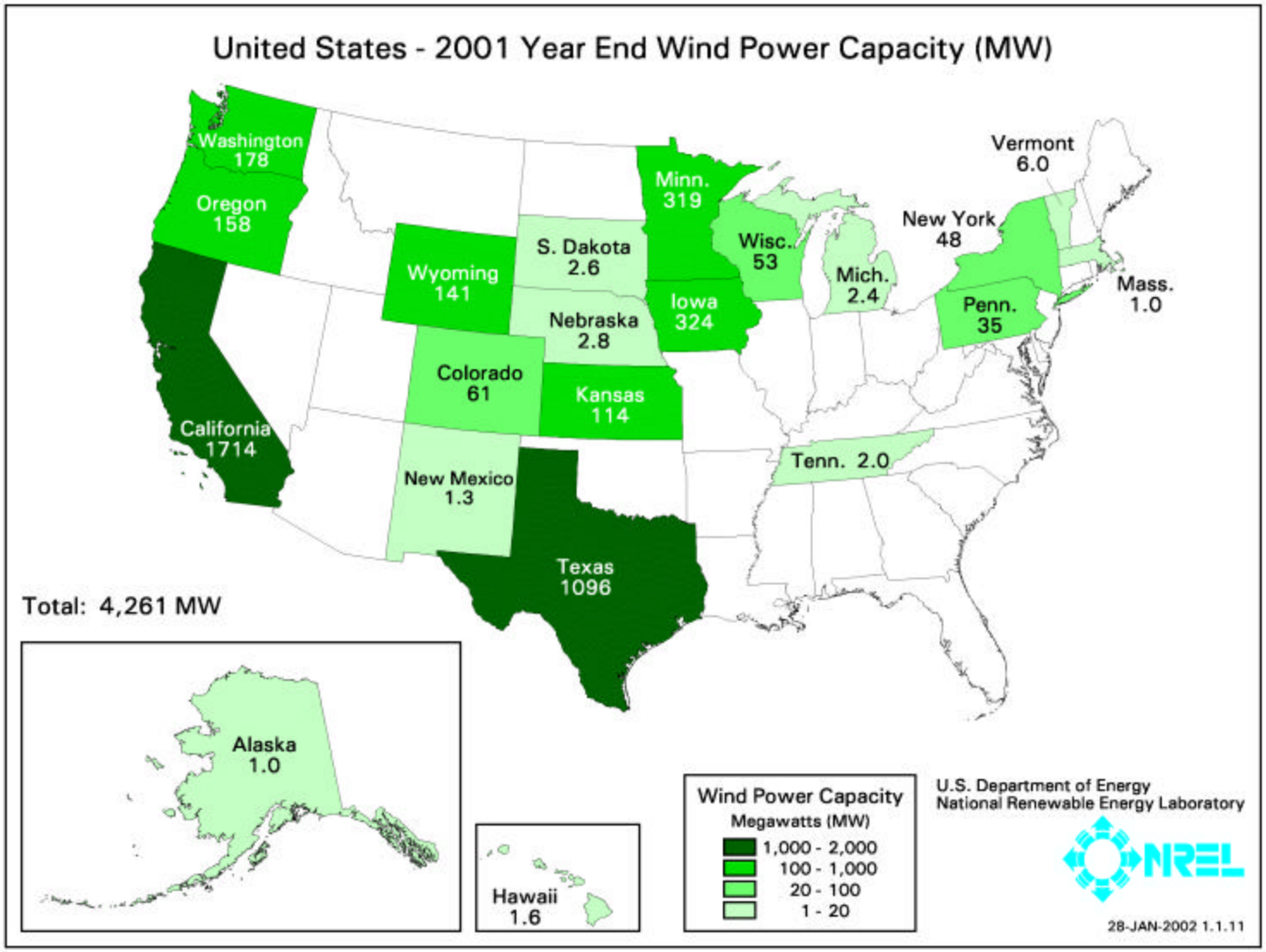
Ed Cannon 303-384-6920

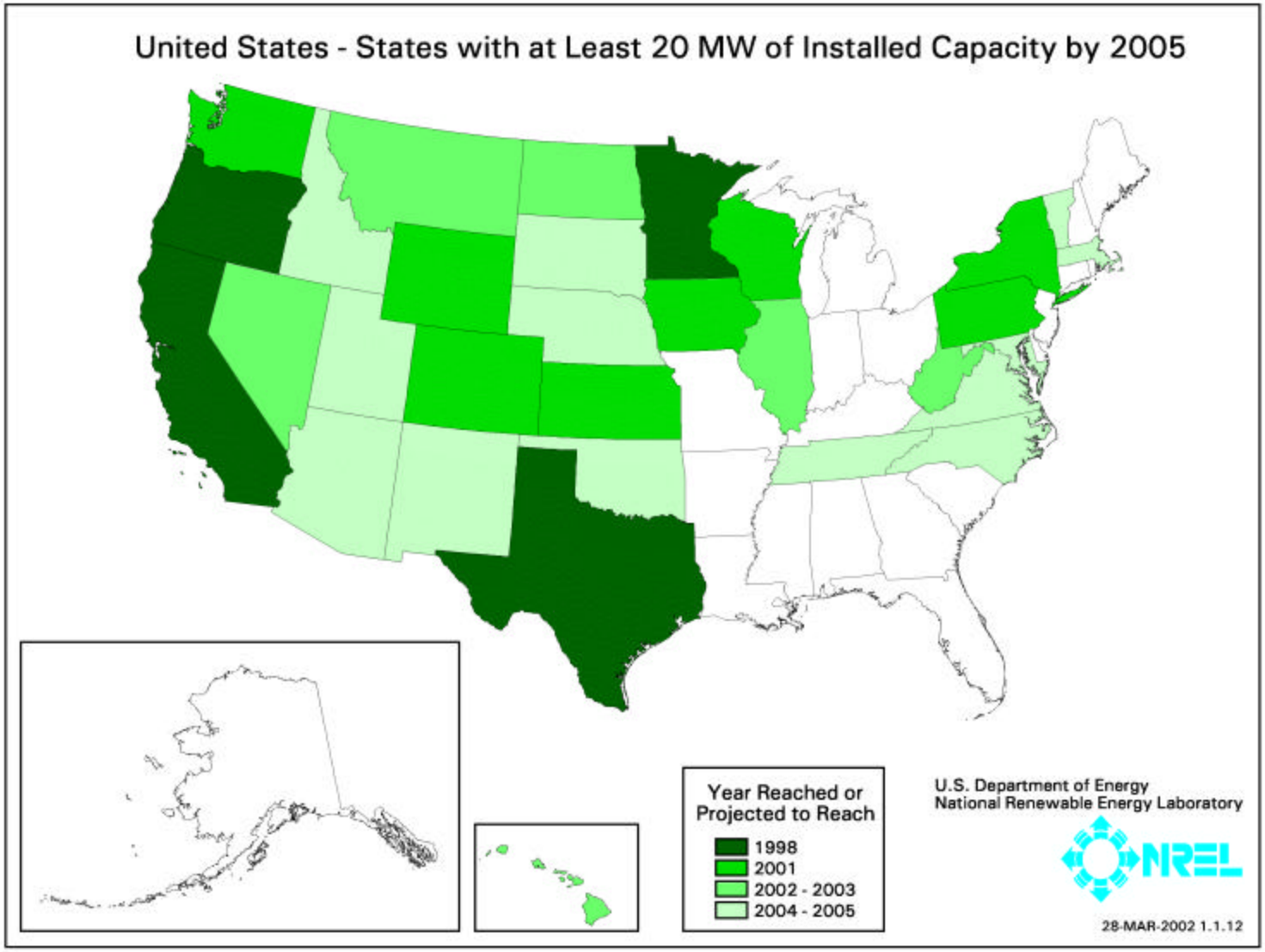
Fax 303-384-7029

e-mail: Ed_Cannon@nrel.gov

National Wind Technology Center

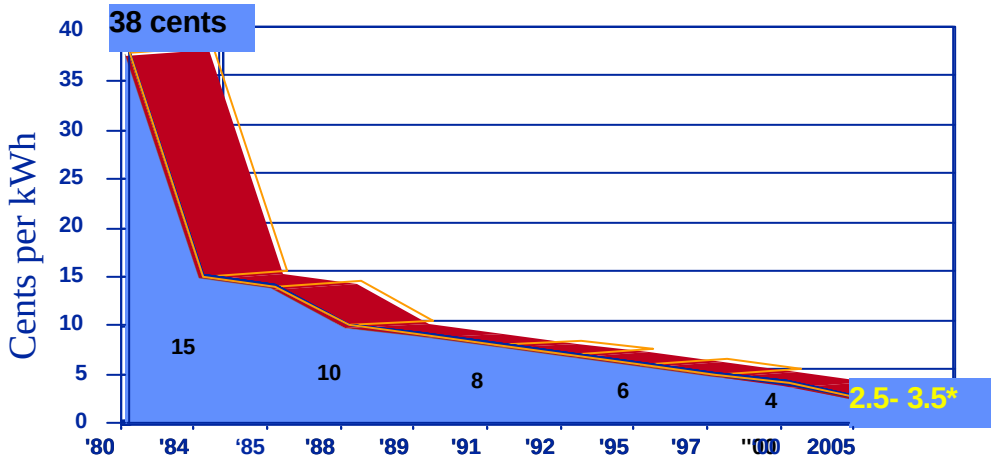
- 80 employees
- Annual budget of ~$34M
- Study the application of wind technology and promote its use
- Provide industry support through testing


United States - 2001 Year End Wind Power Capacity (MW)
Washington 178
Oregon 158
California 1714
Wyoming 141
S. Dakota 2.6
Nebraska 2.8
Colorado 61
Kansas 114
New Mexico 1.3
Texas 1096
Minn. 319
Iowa 324
Wisc. 53
Mich. 2.4
Vermont 6.0
New York 48
Penn. 35
Mass. 1.0
Tenn. 2.0
Total: 4,261 MW
Alaska 1.0
Hawaii 1.6
Wind Power Capacity
Megawatts (MW)
1,000 - 2,000
100 - 1,000
20 - 100
1 - 20
U.S. Department of Energy
National Renewable Energy Laboratory
NREL
28-JAN-2002 1.1.11


United States - States with at Least 20 MW of Installed Capacity by 2005
Year Reached or Projected to Reach
1998
2001
2002 - 2003
2004 - 2005
U.S. Department of Energy
National Renewable Energy Laboratory
NREL
28-MAR-2002 1.1.12

Wind Energy Cost

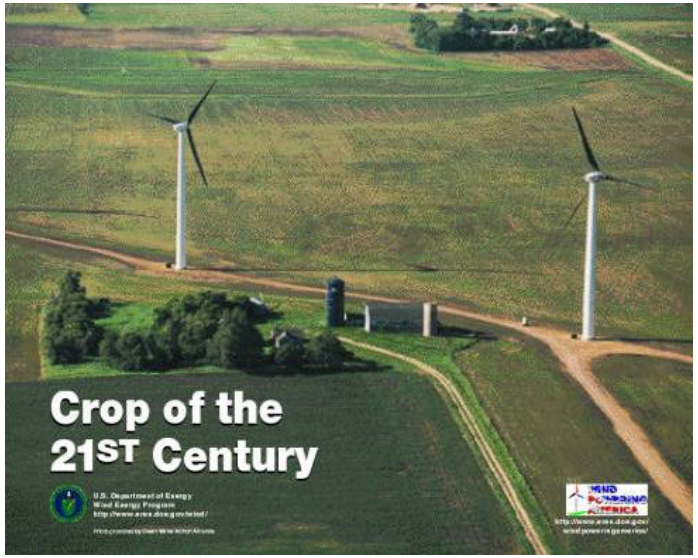
Cost of Wind-Generated Electricity 1980 to 2005, Levelized cents/kWh



Assumptions: Levelized cost at "excellent" wind sites, large project size, not including PTC (post 1994), costs in nominal cents/kWh.

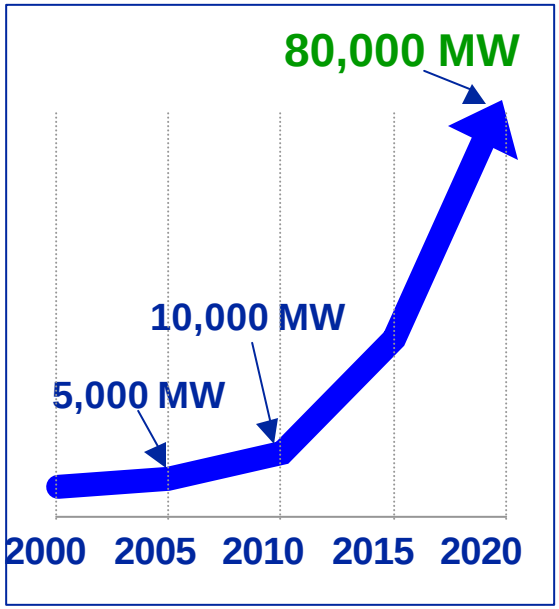
U.S. Wind Market Drivers

- Declining wind costs
- Fuel Price Uncertainty
- Federal and State Policies
- Economic Development
- Green Power
- Energy Security



Wind Powering America Program Goals

- Provide at least 5% of the nation's electricity with wind by 2020
  - Install more than 5000 MW by 2005
  - Have more than 10,000 MW on-line by 2010
- Double the number of states that have more than 20 MW of wind capacity to 16 by 2005, and triple the number to 24 by 2010
- Increase wind's contribution to federal elect. use to 5% by 2010
- *Supplemental goals*
  - *Federal agencies-2.5% RE by 2005; 7 1/2% by 2010*

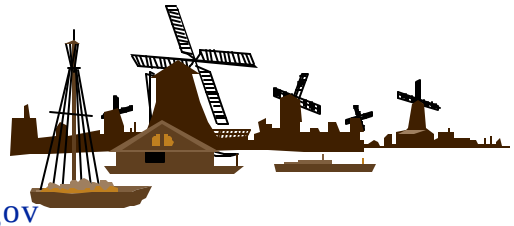


Wind Power Isn't New

- Not a new concept
- Dates to ancient civilizations
- Many advances have brought efficiency up and costs down

Wind Energy

- Wind energy is created by uneven solar heating.
- Wind energy is kinetic energy--mass and momentum. $P = A \times \rho V^3/2$
- Wind energy is proportional to velocity cubed (V^3):
  - If velocity is doubled, power increases by a factor of eight ($2^3 = 8$).
  - Small differences in average speed cause big differences in energy production.

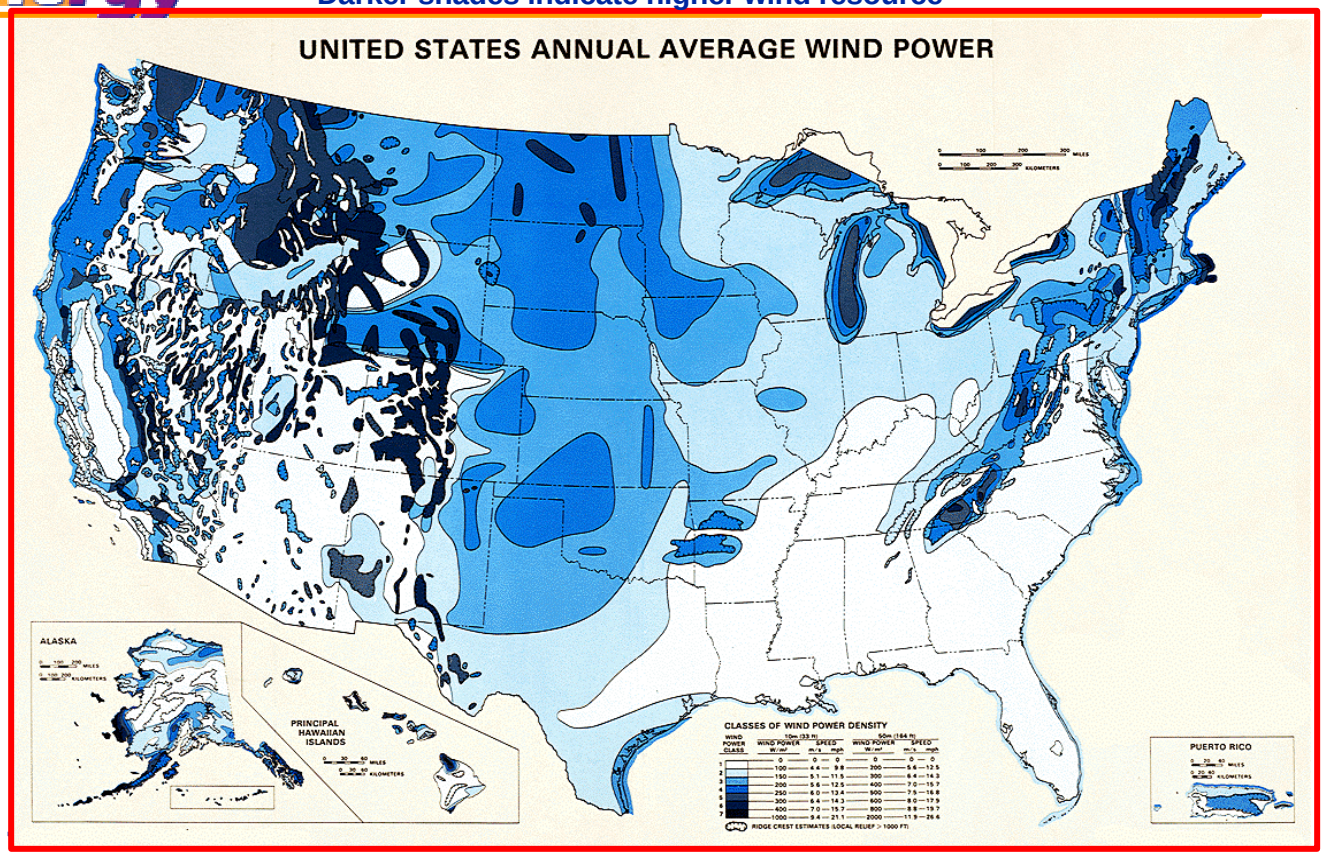


Wind Energy (cont.)

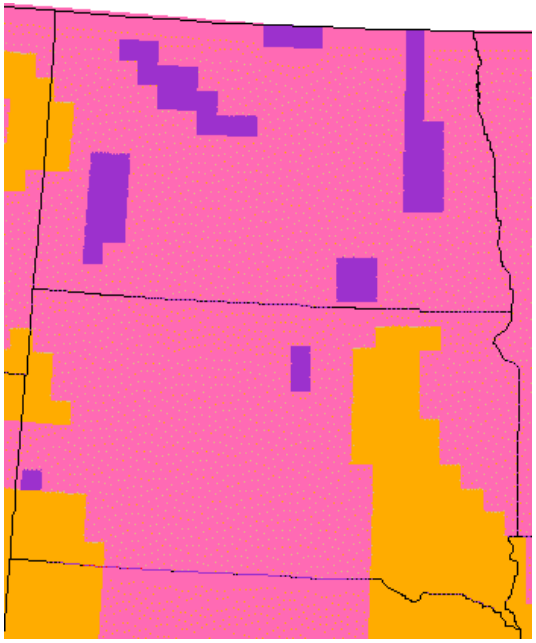
- Wind resources are abundant and widely distributed. Most areas have sufficient wind for off-grid power applications.
- Wind resource maps are published by DOE.
- Wind is intermittent, but follows predictable seasonal patterns.

Average Annual Wind Resource

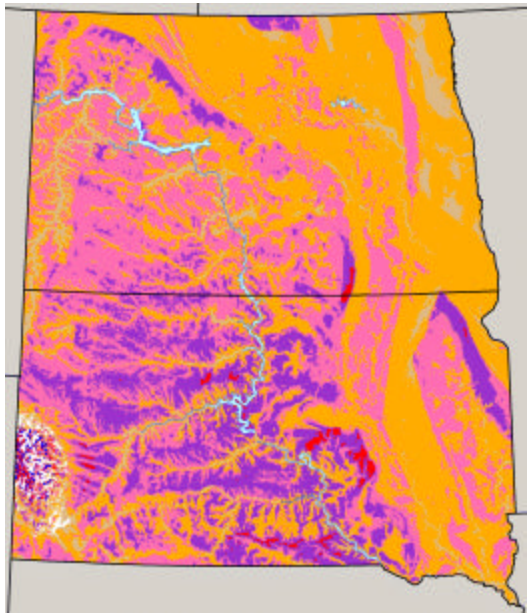
Darker shades indicate higher wind resource



New Detailed Maps Being Created



1987



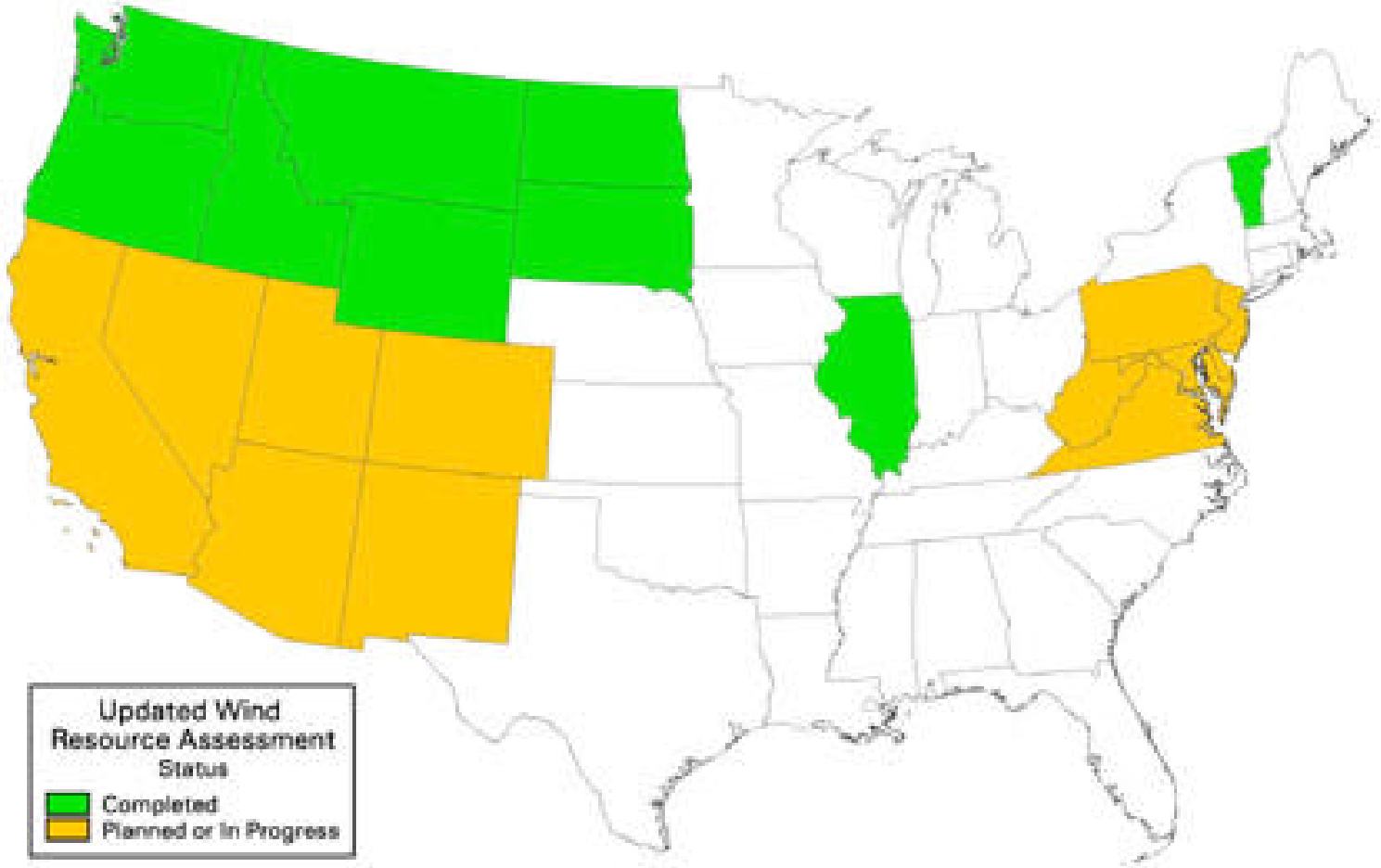
2000

Wind Power Classification

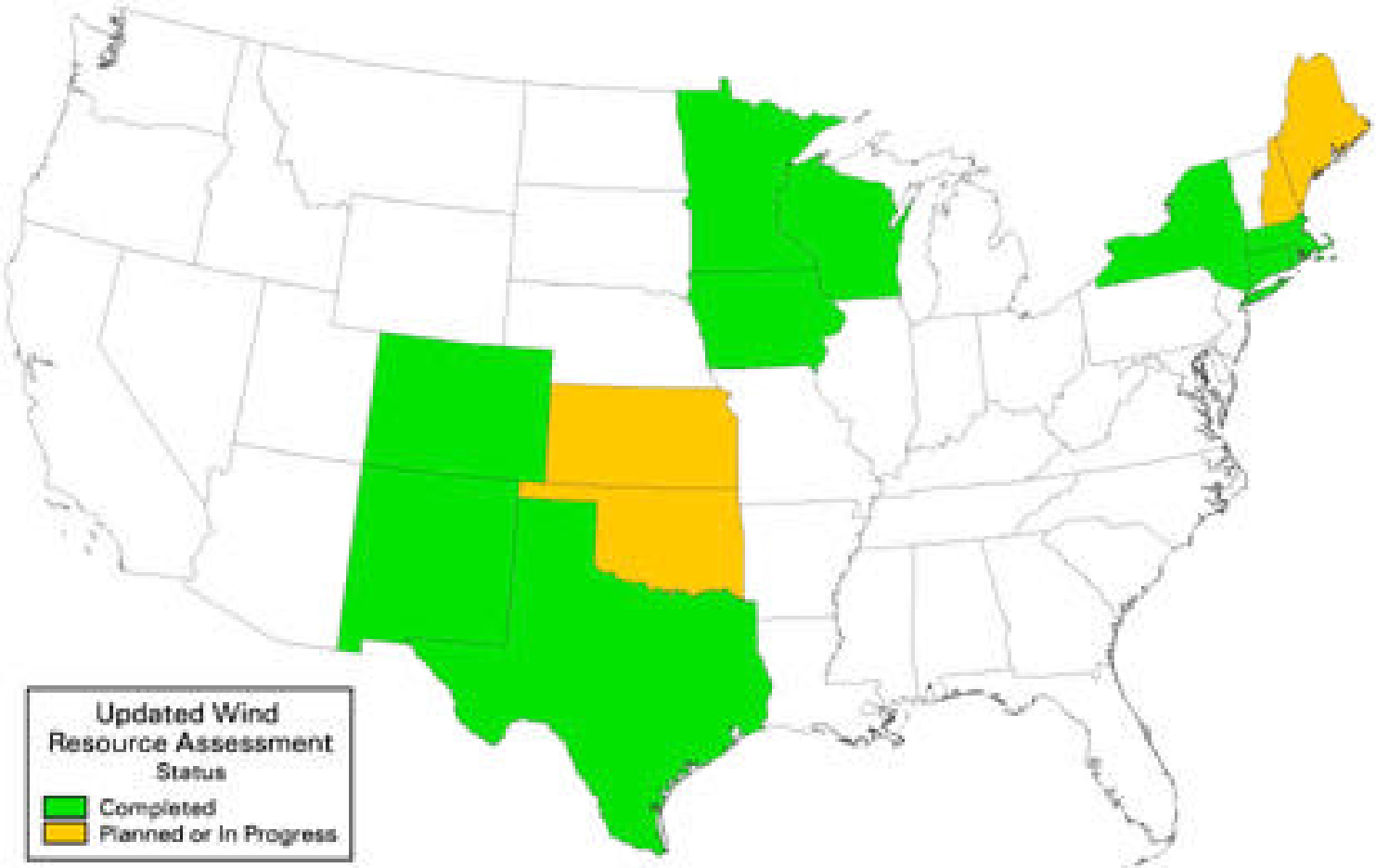
Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m²	Wind Speed* at 50 m m/s	Wind Speed* at 50 m mph
2	Marginal	200 - 300	5.6 - 6.4	12.5 - 14.3
3	Fair	300 - 400	6.4 - 7.0	14.3 - 15.7
4	Good	400 - 500	7.0 - 7.5	15.7 - 16.8
5	Excellent	500 - 600	7.5 - 8.0	16.8 - 17.9
6	Outstanding	600 - 800	8.0 - 8.8	17.9 - 19.7
7	Superb	800 - 1600	8.8 - 11.1	19.7 - 24.8

*Wind speeds are based on a Weibull k value of 2.0

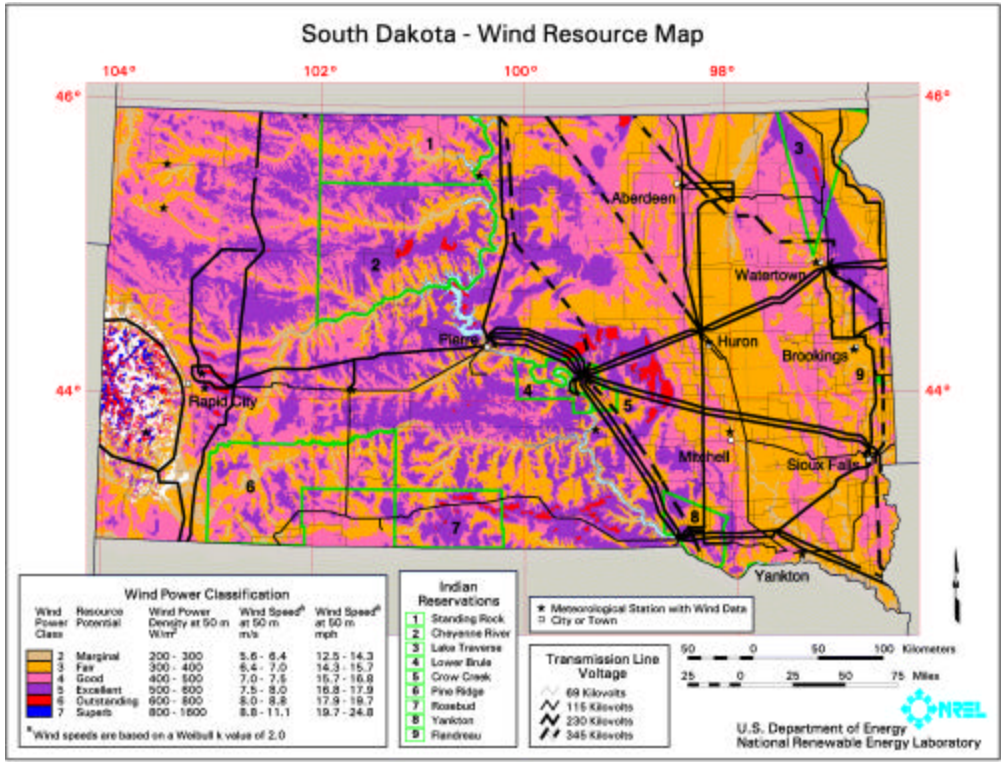
NREL's Updated Wind Resource Assessment Status



Non-NREL Updated Wind Resource Assessment Status



Wind Resource Must Be in "Right Place"



Anemometer Loan Program

Installation at F. E. Warren AFB, WY

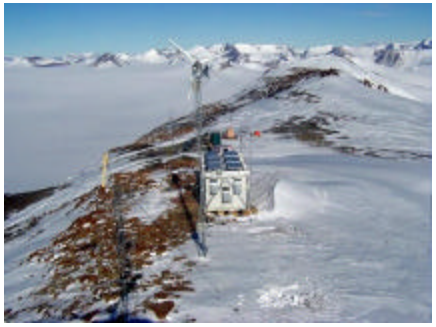
- For initial surveys
- 10 anemometers
- 20 meter poles
- Installation kit
- Pull data chips monthly and sent to NWTC for analysis
- Contact Ed Cannon or Tony Jimenez at NWTC 303-384-6900

Large and Small are Different

Large Turbines – 100 kW to 1.5+ MW
- •Installed in “wind farm” arrays
- •Provide power to utility grid
- •Require 13 mph average wind sites
- •Large investment requires careful analysis

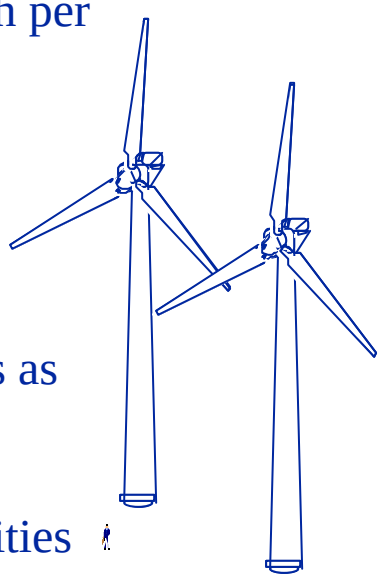
Small Turbines – 0.5 to 100 kW
- •Installed in off-grid and facility-specific on-grid applications
- •Provide power using back-up generation or storage
- •Designed for reliability, low maintenance
- •Require 9 mph average wind sites

Large and Small Federal Wind Turbines



Large Wind Turbines

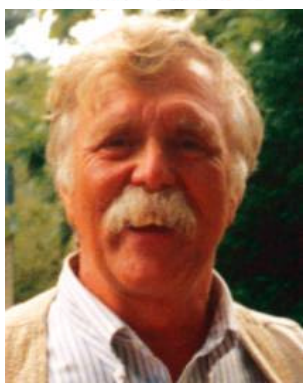
- U.S. windfarms: >4,200 MW and 8 billion kWh per year.
- Costs are down to <$1,000/kW installed.
- Operating costs are down to <1 cent/kWh.
- At good wind sites, costs of energy below 5 cents/kWh are possible.
- Typical turbine is 750 to 1500 kW, but turbines as low as 50kW are available.
- Typical installation is > 1 MW, but individual turbines and small clusters are installed at facilities to reduce utility bills.



Palm Springs, CA

"Our customers wanted this wind program and it was our job to deliver it. It has turned out to be a huge source of community pride. The turbines are a visible landmark showing the Moorhead Community's commitment to a better world for our children."

Christopher Reed, Moorhead Public Service, Moorhead, Minnesota



"Wind is a homegrown energy that we can harvest right along side our corn or soybeans or other crops. We can use the energy in our local communities or we can export it to other markets. We need to look carefully at wind energy as a source of economic growth for our region"

David Benson, Farmer and County Commissioner, Nobles County, Minnesota

June 2-5, 2002

www. energy2002.ee.doe.gov

Large Wind Turbines (cont.)

- Large wind turbines should be considered when:
  - Costs of conventional power exceed 8 cents/kWh.
  - Annual consumption exceeds 100,000 kWh.
  - Wind resources are 5.6 m/s (12.5 mph; DOE Class 4) or better.
  - At least 40 acres of land are available for installation per MW installed capacity.

Large Wind Turbine Follow-Up

- Feasibility studies and wind resource monitoring are usually required.
- Purchasing options: direct equipment purchase or power purchase agreement.
- For listings of consultants, manufacturers, and project developers, use the membership directory of the American Wind Energy Association.

Federal Wind Studies

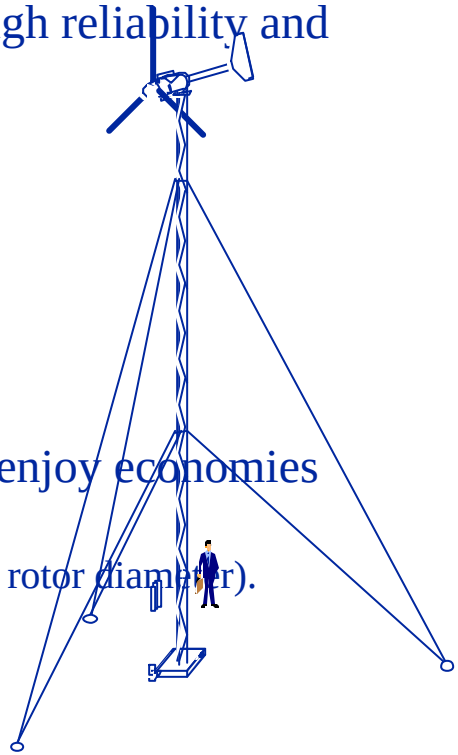
- Bureau of Land Management, Forest Service, Native American Lands
  - Secretary of the Interior Norton directed that process be streamlined
  - BLM screened all planning areas to identify those with highest RE potential
  - Accelerating revised land use plans
  - Training local offices on renewable energy
  - Seeking showcase projects for quick success

Federal Wind Studies (cont.)

- Department of Defense
  - 2002 Military Construction appropriation contained $6 million set aside
  - Screen all CONUS bases for renewable energy projects on or near military bases
  - Air Force lead
    - Air Force -- Wind
    - Army -- Solar
    - Navy -- Geothermal

Small Wind Turbines

- Small turbines are specifically designed for high reliability and low maintenance:
  - Simple designs: only 3-4 moving parts.
  - Little or no scheduled maintenance.
  - O&M costs below 1cent/kWh.
  - Automatic operation under all conditions.
- Small turbines are operating in all 50 states.
- Small turbines are relatively inexpensive and enjoy economies of scale:
  - $1.90/watt (turbine only) for a 500-watt unit (1.7m rotor diameter).
  - $1.60/watt (turbine only) for a 10,000-watt unit (7m rotor diameter).



Small Wind Turbines (cont.)

- Small turbines require average wind speeds above 4 m/s (9 mph)--most places fit the bill.
- Typical cost of energy is 7 cents to 20 cents/kWh at the turbine bus.
- With storage, power conditioning, and backup generation, the cost of firm alternating current power at off-grid sites is roughly doubled.

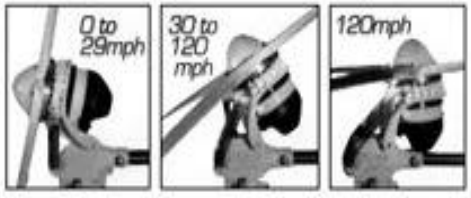
Small Wind Turbines (cont,)

- Small wind turbines generally compete in markets with high conventional energy costs--typically 12 cents to 70 cents/kWh:
  - Remote facilities and residences.
  - Telecommunications, navigation aids, etc.
  - Miscellaneous remote site loads (e.g., environmental remediation).
  - Water pumping, desalination, ice making, etc.
  - Diesel generator retrofits.
  - Utility bill reduction.
  - Greening projects.
- Small turbines are often used with photovoltaics. Such hybrid systems reduce seasonal variations.

Examples of modern wind turbines:

Southwest Windpower
Windseeker

- 2 or 3 blade designs
- 500W (400W marine model)
- vertical furling
- unregulated versions available



Examples of modern wind turbines

- Bergey Windpower Excel
  - 48V to 120V models
  - 7kW rated power
  - 3 phase AC current
    - rectified at controller (near batteries)
    - voltage regulated at controller
  - 3 pultruded blades (constant chord)
    - 7m rotor

Reliability and Maintenance

- Turbines operate unattended and automatically, even in severe weather.
- Reliability and maintenance requirements are design specific. Look for:
  - Simplicity of design.
  - Fiberglass blades.
  - Direct-drive, brushless generators.
  - Heavy-weight structural elements.
  - Corrosion-resistant materials and finishes.

Important: Check supplier reputations!

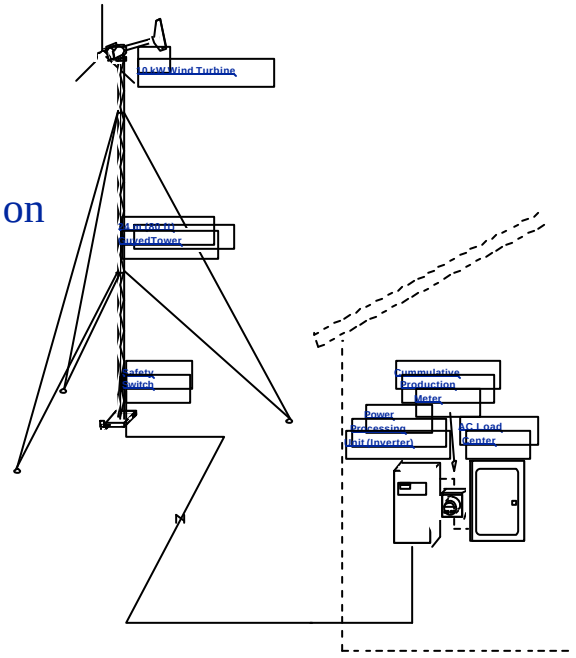
Reliability and Maintenance (cont.)

- Best available units require no scheduled maintenance and can operate for 3 to 6 years without attention:
  - Inspection recommended every 2 years.
  - At 3 to 6 years, blade leading edge tape must be renewed.
- Typical design operating life is 30 years.

  (Some small turbines have been operating for more than 60 years!)

Grid-Intertie System

- 3 to 20kW variable speed wind turbine.
- Power electronics (inverter) converts output to 240 VAC, 1ϕ.
- No batteries.
- Grid-connect through dedicated breaker on alternating current load center.
- Turbine production reduces purchase of utility power.
- Excess production sold to utility.
- System shuts down during outage.
- Easily retrofitted to current facilities.
- Fits “distributed generation” concept.

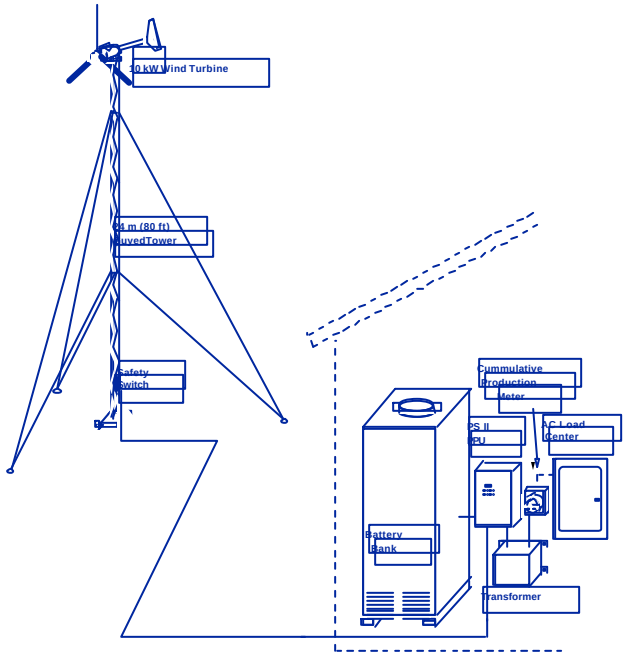


Case Study: On-Grid Farm with Wind System

- Clover Valley, Minnesota
- Utility bill reduction
- World Power Technology Whisper 3000 wind turbine, 3.0 kW, 14.8 ft rotor, 50 ft tower

Advanced Grid-Intertie System

- Incorporates small battery bank (~50kWh).
- Ability to isolate service and provide household or facility uninterrupted power supply.
- Ability to deliver firm on-peak power for peak shaving.
- Battery charging from both wind and utility grid.



Case Study: On-Grid Home with Wind/PV System

Rural Boulder County, Colorado, net metering for utility bill reduction

World Power Technology Whisper 3000 wind turbine, 3 kW, 14.8 ft rotor, battery-charging, 23 ft tower

BP Solar model 590 PV panels, 8.6 kW

54 V DC battery bank

Pair of Trace SW5548 inverters, 240 V AC, 1 phase, 11 kW total

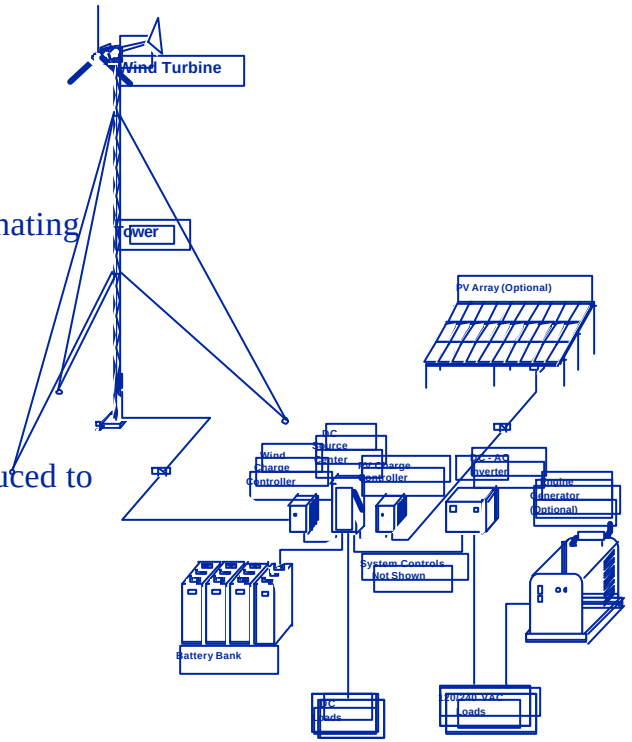
Total installed cost ~$100,000

All electric home including heat pump and electric car

Passive-solar,super-insulated home design

Wind/Photovoltaic/Diesel Hybrid Systems

- One or more 0.5 to 20 kW variable speed wind turbines.
- Optional solar.
- Lead-acid batteries, flooded or sealed type.
- Static or rotary inverters for direct current/alternating current conversion.
- Backup diesel generator for low wind periods.
- Renewables typically supply 60% to 85% of energy.
- Provide 24 h/d power with diesel run times reduced to ~10%.
- Very small systems (<5 kWh/d) usually have photovoltaics and no diesel.

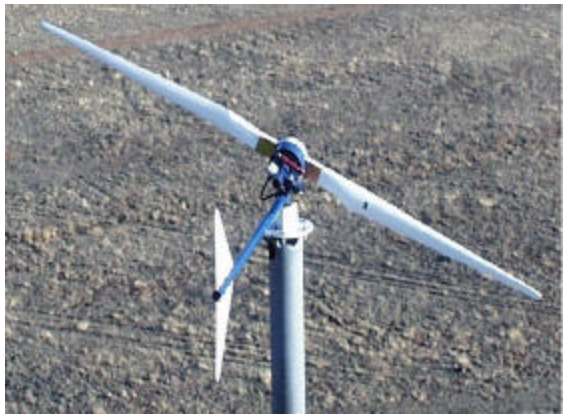


FAA Beacon Lake Chandalar, AK

- FAA aircraft navigation beacon at Chandalar Lake in Brooks Range, northeast AK.
- Accessible only by air.
- Previously powered by diesel generators--fuel flown in.
- Decided on an all-renewables system in the 1999.
- Two Bergey 7.5 kW turbines on 30 m (100 ft) guyed-lattice towers, 5 kW solar array, 48 VDC sealed battery bank, switchgear, and two Trace sine wave inverters.

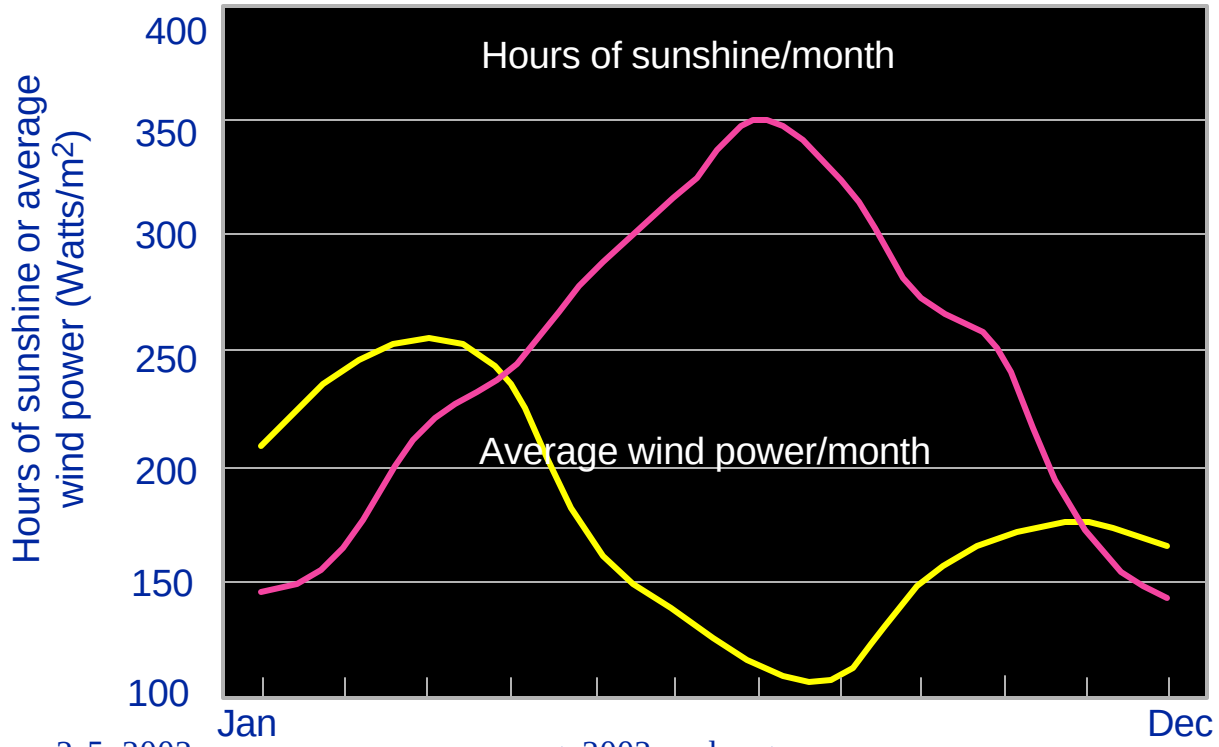
Sunwize Power System

- Whisper 3000 wind turbine
- 1.8 kW PV (Siemens)
- 5.8 kW diesel generator
- 25.6kWh battery bank
- 2-SW4048 4kW inverters



Solar and Wind Resources are Complimentary

Data from SE Iowa



Hybrid Systems Make Sense (cont.)

- Together, they provide a more reliable and cost-effective power system than is possible with wind, PV, or diesel alone.
- Wind and solar often have seasonally complementary resources.
  - Summer: low wind/high solar.
  - Winter: high wind/low solar.

Applying Small Wind Turbines (cont.)

- Small wind turbines should be considered when:
  - The grid must be extended more than 1 km (0.62 miles), or
  - Costs of conventional power exceed 12cents/kWh,
  - Annual consumption exceeds 300 kWh, and
  - Wind resources are 4.4 m/s (9.8 mph; DOE Class 1) or better.

Design Procedure

1. Determine daily load requirements:

   ___Alternating current or direct current kWh/d;
   ___Meter^3 water/d at head of ____ meters.

2. Convert off-grid alternating current requirements to direct current: divide alternating current kWh by 0.7.

3. Determine monthly average resource values:
   - For hybrids, need wind (m/s) and solar (kWh/m^2/d) resources.

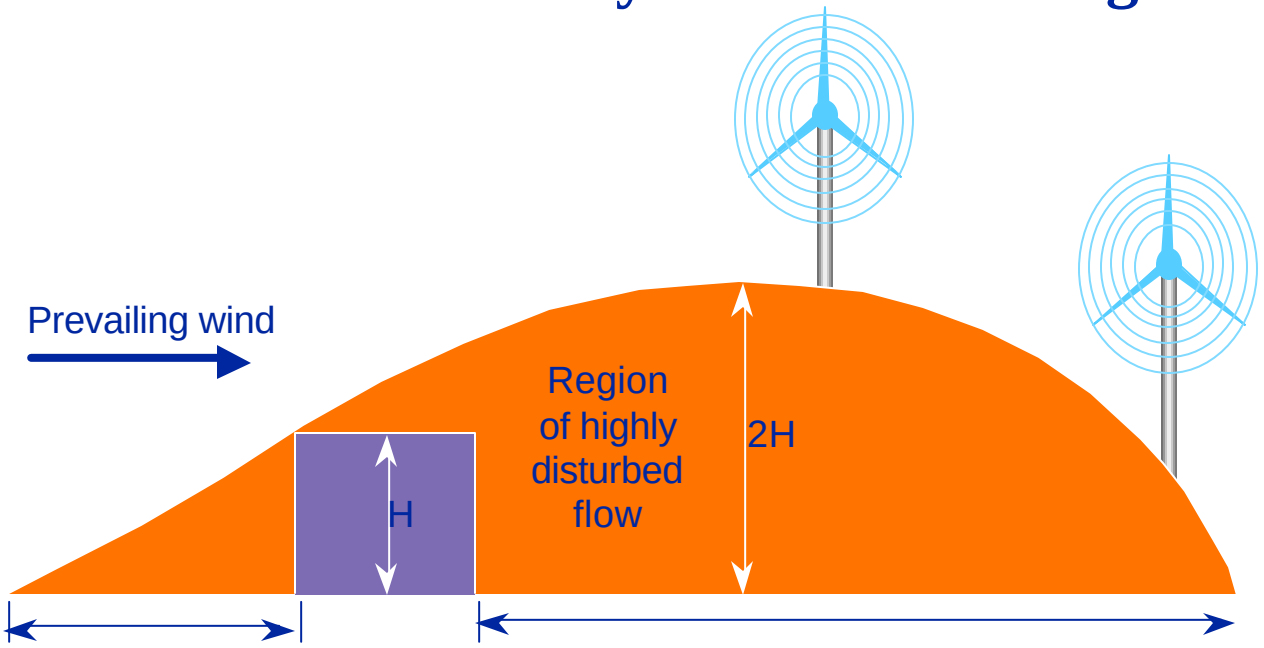
Design Procedure (cont.)

4. Use spreadsheet model or tabular/graphical performance data to evaluate daily performance of candidate wind turbines:

   - Adjust wind speeds for tower height.
   - Other adjustments: altitude, wind pattern (Weibull K), turbulence.

Micro-Siting Example:

Obstruction of the Wind by a Small Building

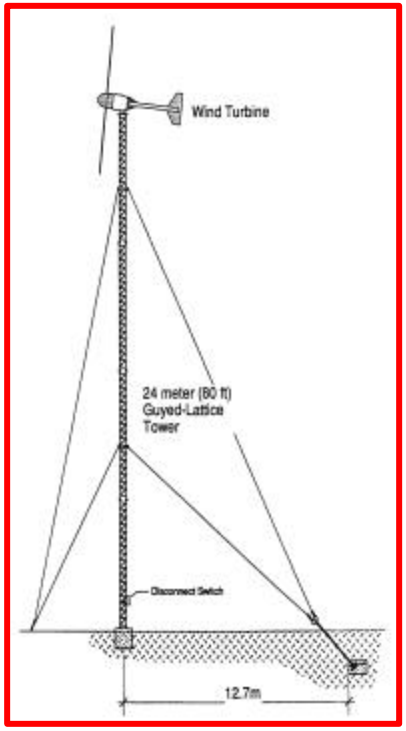


Design Procedure (cont.)

5. Iterate component selection to achieve design goal(s):
   - Usually minimum cost of energy, but also capital cost, payback hurdle point, renewables fraction, backup fuel consumption / emissions, etc.
6. Finalize design and complete selection and sizing of ancillary (balance of systems) equipment.
7. Prepare budget and specifications.

Small Wind Turbine Towers

- Guyed lattice and tube towers are the least expensive and most commonly used towers for small wind turbines
- Tilt-up versions are available for easier installation and maintenance
- Adequate space is needed for the guy wires and their anchors
- Free-standing towers are used where space is limited



Key Points

- Small wind turbines are a reliable, proven, widely used **mature technology** for remote site power.
- Wind resources sufficient for small wind turbines are available at **most** locations.
- Energy costs from small wind turbines are **much less** than photovoltaics and **usually less** than diesel generators.
- Complete support, from design to installation, is available from industry.

Key Points (Cont.)

- Feasibility studies and wind resource monitoring are not usually required.
- Purchasing options:
  - Direct equipment purchase.
  - Power purchase agreements are rare (but possible).
- For listings on consultants, manufacturers, and project developers, use the membership directory of the American Wind Energy Association.

Resources: On The Web

Wind Powering America:
http://www.eren.doe.gov/windpoweringamerica
AWEA Web site: http://www.awea.org
NREL Web site: http://www.nrel.gov
NWTC Web site: http://www.nrel.gov/wind